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A Taxonomic Study of *Asarum celsum* and Its Allies (Aristolochiaceae) on Amami-oshima, Southwestern Kyushu, Japan

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Asarum celsum (Aristolochiaceae, section *Heterotropa*) and its allies were investigated on Amami-oshima, southwestern Kyushu, Japan. The results of morphological studies showed that three taxa, *A. celsum*, *A. tabatanum*, sp. nov., and *A. nazeanum*, sp. nov., with distinct morphological features and separate geographical ranges could be recognized. *Asarum tabatanum* is characterized by a larger globular-tubiform calyx tube, the inner surface of which is a complicated network of 19 to 24 longitudinal ridges and interconnecting transverse ridges, and by longer stylar protuberances. *Asarum nazeanum* is distinguished from *A. celsum* and *A. tabatanum* by its large calyx tube spreading apically, sharp and prominent longitudinal and transverse ridges, and wider calyx tube entrance.

Key words: Amami-oshima, Aristolochiaceae, *Asarum nazeanum*, *Asarum tabatanum*, morphological variation, new species, taxonomy

Asarum L., s.lat. (Aristolochiaceae) is a diverse genus of perennial herbs distributed in eastern Asia, Europe, and North America, and composed of more than 90 species (Huang *et al.* 2003). Its floral diversification is bewildering, especially in China, Taiwan, and Japan (Sugawara 1987, Lu & Wang 2009). In the broad sense, approximately 50 species have been reported from the Japanese Archipelago (Sugawara 2006b), and each usually occurs in a narrowly restricted area (Hiura 1978, Hotta *et al.* 2005).

In 2008, Mr. M. Tabata informed me of some unknown plants of *Asarum* on Amami-oshima. Amami-oshima is located roughly halfway between the islands of Okinawa and Kyushu, Japan. Based on his report, I examined the unknown plants along the Asato River on Amami-oshima, where six species of *Asarum* have already been reported (Hatusima & Yamahata 1988, Hotta *et al.* 2005). Although the unknown plants were growing with *A. fudsinoi* T. Ito and *A. lutchuense* (Honda) Koidz., they were easily distinguished from those to species. *Asarum fudsinoi* and *A. lutchuense* are characterized by their large, lustrous leaf blades and long petioles, and by the large calyx tube peculiar to each species (Sugawara 2006b), and were therefore easily distinguishable from the unknown plants. In their smaller, triangular-ovate, lusterless leaves with sparsely hispid margins and tubular calyx tube with a narrow entrance and lamellate appendages between the orifice and the calyx lobes, the unknown plants appeared to be allied with *A. celsum* F. Maek. ex Hatus., which is known from the southern end of Amami-oshima. *Asarum celsum* was described from plants on Yuwan-dake (Hatusima & Yamahata 1988), and its occurrence was subsequently reported from several mountains, including Yakugachoboshi-dake and Kinsakubaru (Hatusima & Yamahata 1988, Hotta *et al.* 2005). In preliminary examinations I found floral variation within populations of *A. celsum* that made its circumscription unclear.

To determine the identity of the unknown plants and to define the limits of *Asarum celsum* I conducted population and morphological studies.

Based on my findings I here proposed two new species of *Asarum*.

Materials and Methods

The plants of *Asarum* examined in this study grow in evergreen broadleaved forests dominated by *Castanopsis sieboldii* (Makino) Hatus. ex T. Yamaz. & Mashiba on Amami-oshima, southwestern Kyushu, Japan, and flower in late February and March (Fig. 1). I examined eight populations in total: six of *A. celsum* and two of the un-

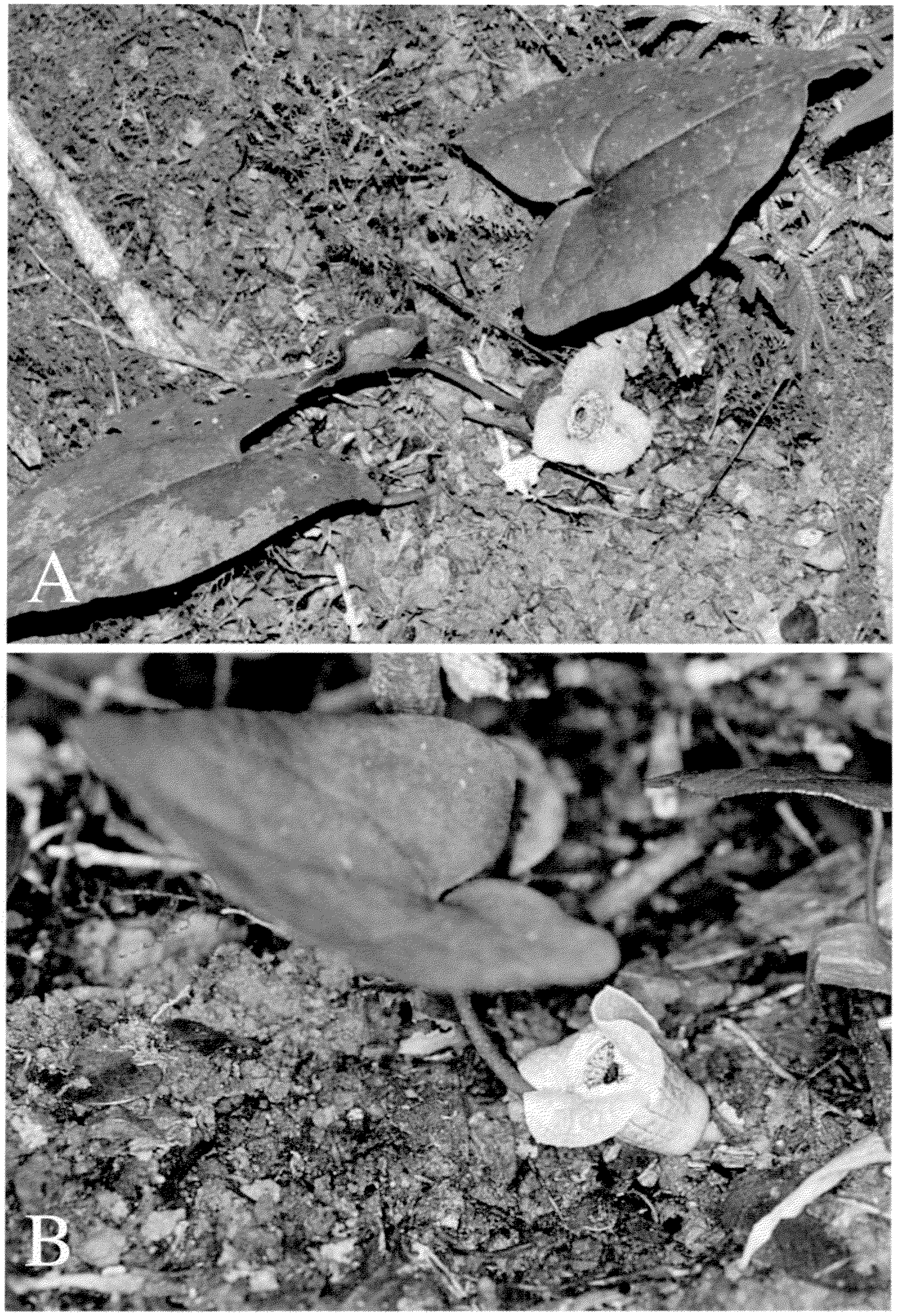

FIG. 1. A: *Asarum tabatanum*, Wase-I population along the Asato River, Amami-oshima. B: *A. nazeanum* at Kinsakubaru, Amami-oshima.

known plants (Fig. 2). Detailed collection data, including number of individuals examined in each population are shown in Table 1. Voucher specimens of plants from each population were deposited in the Makino Herbarium (MAK), Tokyo Metropolitan University, Tokyo, Japan (Table 1).

In all populations the following characters were measured: calyx tube length, calyx tube width at its widest point, diameter of calyx tube entrance, calyx lobe length, calyx lobe width, number of longitudinal ridges on inner surface of a calyx tube, anther length of inner stamen, anther length of outer stamen, and length of stylar protuberance. The flowers were collected from natural habitats and fixed in 70% ethanol alcohol, then measured with the aid of a binocular microscope following the procedures of Sugawara (2003).

Results and Discussion

Morphological variation in eight populations

The floral characters showed remarkable differences among the populations examined in this study. In the shape of the calyx tube, two types were easily recognized: a calyx tube spreading apically in the Kinsakubaru population (Pop. 6) and a campanulate calyx tube in other populations (Fig. 3).

The calyx tubes also differ in size among the populations. Fig. 4 is a scatter diagram of length and width of the calyx tubes examined in the eight populations. Plants from the Kinsakubaru population (Pop. 6) and from the Wase-I and -II populations (Pops. 7 & 8) deviate from those of the other populations in having a larger calyx tube.

Reticulate ridges on the inner surface of a calyx tube vary among the plants in number of both longitudinal and transverse ridges. Attention was focused to the number of longitudinal ridges extending from the base to the upper region of the calyx tube, since the number of ridges has been

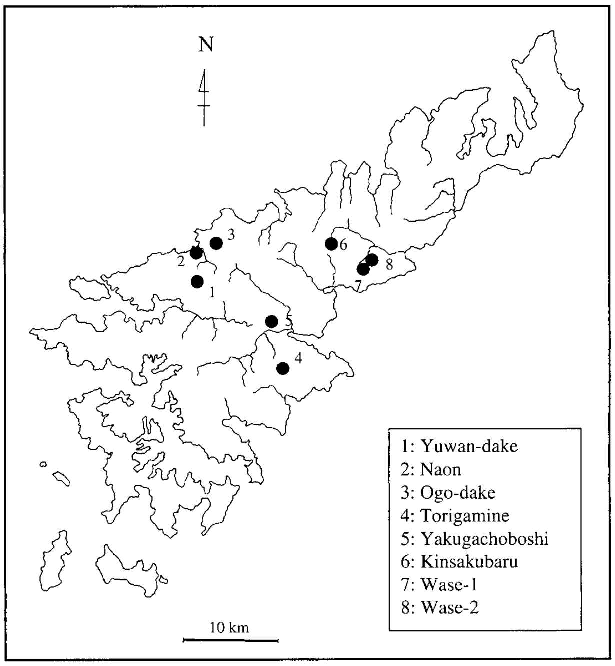

FIG. 2. Map showing localities of eight populations of *Asarum celsum*, *A. tabatanum* and *A. nazeanum* on Amami-oshima, southwestern Kyushu, Japan. Number corresponds to population in Table 1.

TABLE 1. Collection sites, number of plants examined, and voucher specimens for morphological observations of eight populations of *Asarum* from Amami-oshima.

Population (Number of plants examined)	Voucher specimens deposited in MAK
1. Kagoshima Pref.: Yamato-son, Yuwan-dake, alt. 680–690 m (7)	MAK361295
2. Kagoshima Pref.: Yamato-son, Naon, alt. 50–60 m (6)	MAK366251, 366252
3. Kagoshima Pref.: Yamato-son, Ogo-dake, alt. about 520 m (4)	MAK380100
4. Kagoshima Pref.: Amami City, Mt. Torigamine, alt. 450–460 m (8)	MAK366253
5. Kagoshima Pref.: Uken-son, Mt. Yakugachoboshi, alt. about 400 m (6)	MAK397480
6. Kagoshima Pref.: Amami City, Kinsakubaru, alt. 350–400 m (12)	MAK361294a, 361294b
7. Kagoshima Pref.: Amami City, near Wase Pass I, alt. 150–200 m (7)	MAK397482
8. Kagoshima Pref.: Amami City, near Wase Pass II, alt. 150–200 m (6)	MAK397481

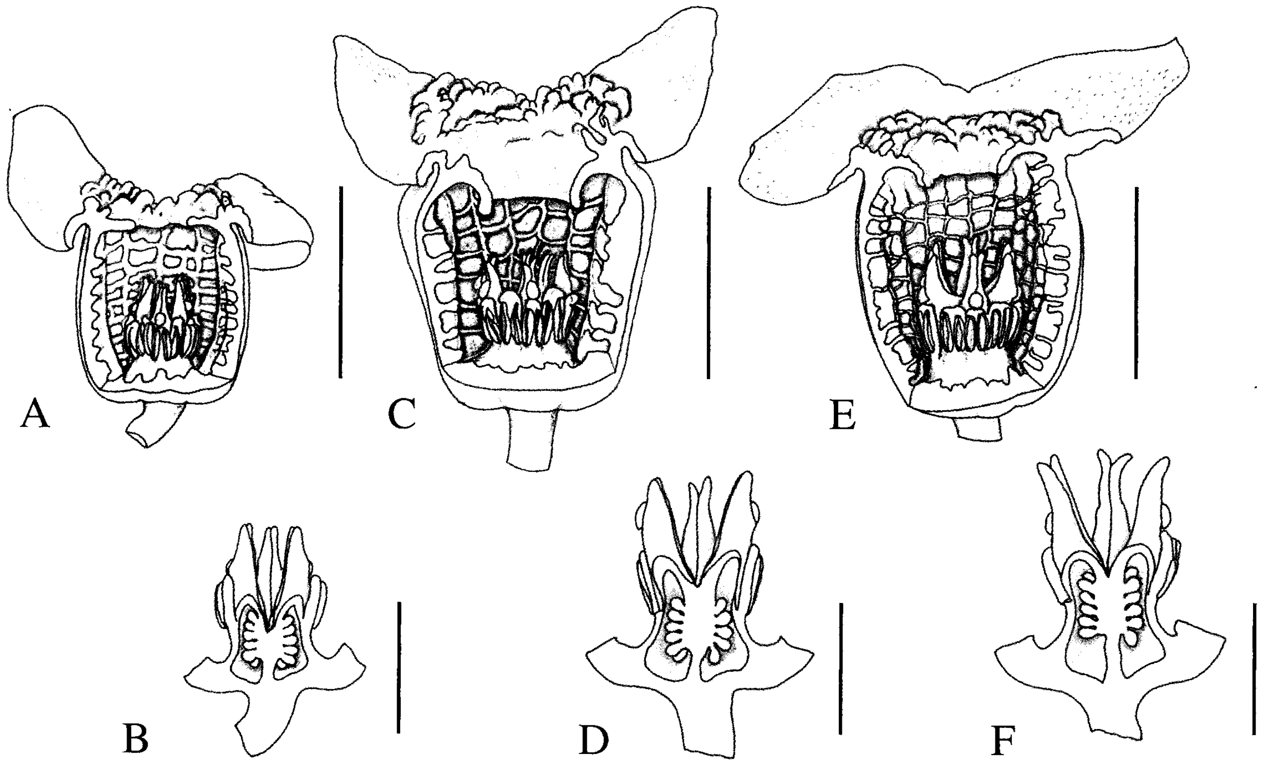

FIG. 3. Three representatives from eight populations of *Asarum celsum* and its allies. A, B: *A. celsum*, flower and longitudinal section of mature flower showing ovary position from Yuwan-dake population. C, D: *A. nazeanum*, flower and longitudinal section of mature flower showing ovary position from Kinsakubaru population. E, F: *A. tabatanum*, flower and longitudinal section of mature flower showing ovary position from Wase-I population. Scale bars represent 10 mm in A, C, E, and 5 mm in B, D, F.

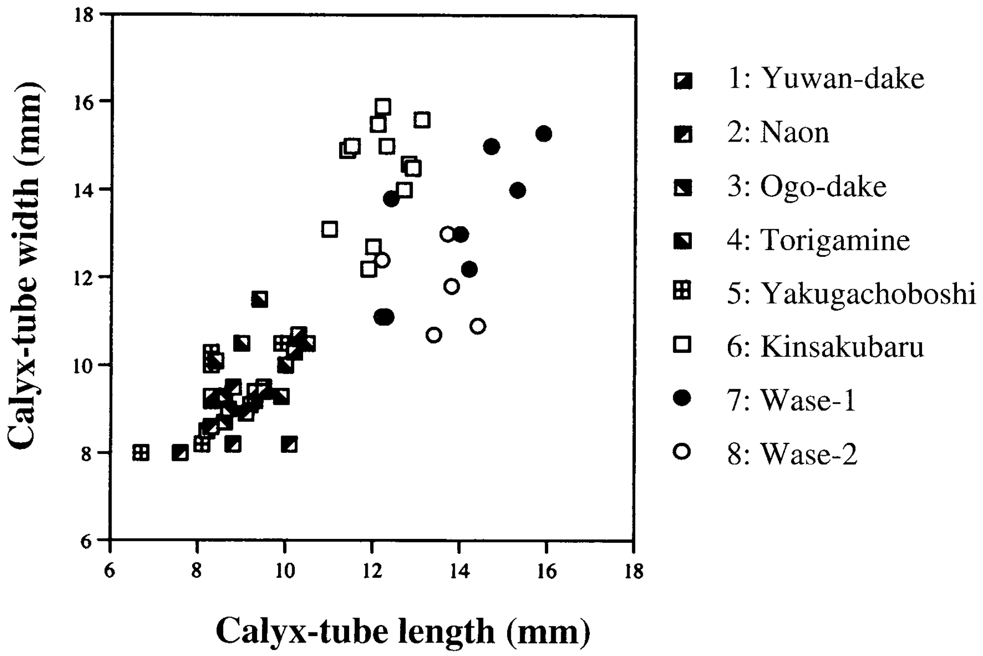

FIG. 4. Scatter diagram showing relationship between length and width of calyx tube.

regarded as being useful in the taxonomy of *Asarum* (Sugawara 1992, 1998, 2006a,b). The frequency distribution of individuals with different numbers of longitudinal ridges in eight populations is shown in Fig. 5. Based on the number of longitudinal ridges, the plants are easily divisible into two groups; one with ridges from 10 to 15, and another with ridges from 19 to 24. The former occurs in plants from six populations (Pops. 1–6), and the latter occurs in the unknown plants in the Wase populations (Pops. 7 & 8).

Attention was also paid to the configuration of the reticulate ridges. Within the eight populations examined, the Kinsakubaru population (Pop. 6) was easily distinguished from the others on the basis of the configuration of the ridges. In the Kinsakubaru population, the ridges are sharper and more prominently keeled than in the other populations (Fig. 6B). In the Wase populations (Pops. 7 & 8) the ridges are sharp but not prominently keeled (Fig. 6C). In populations 1–5 the ridges are obtusely keeled (Fig. 6A).

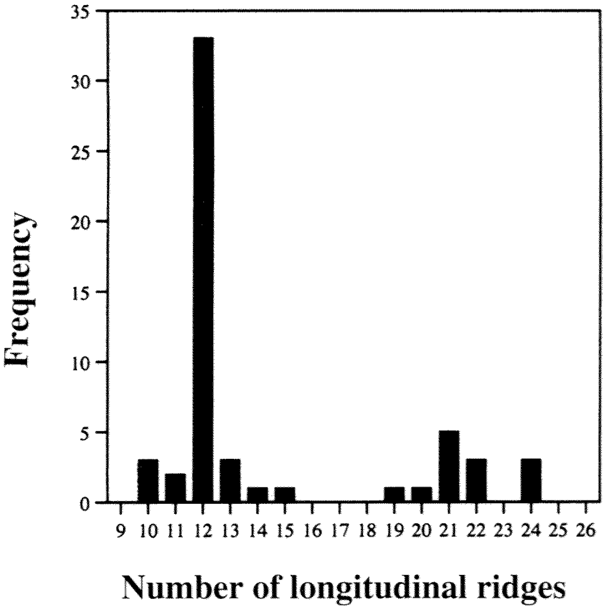

FIG. 5. Frequency distribution of plants with different number of longitudinal ridges on inner surface of calyx tube.

Taxonomic consideration

From the morphology, the populations can be assembled into three groups. Each of the three groups is distinct morphologically and occupies a definite geographical range. On this basis, I am recognizing three species. Although the three species are distinct, they may be closely related in view of their overall similarity. Among them, *Asarum celsum* occurred in five populations (Pops. 1–5) on the southern parts of the island, which includes the type locality (Hatusima & Yamahata 1988). The second taxon, here named *A. nazea-*

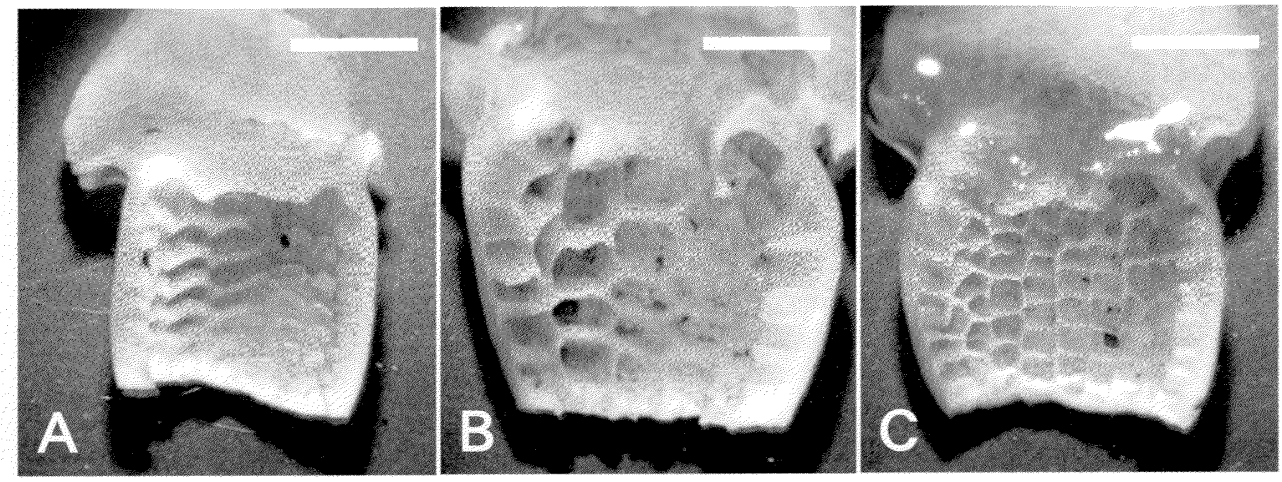

FIG. 6. Reticulate ridges on inner surface of 1/3 of calyx tube. A: *Asarum celsum*, Yuwan-dake population, ridges obtusely keeled. B: *A. nazeanum*, Kinsakubaru population, ridges sharply and prominently keeled. C: *A. tabatanum*, Wase-1 population, ridges numerous, complex, and sharply but not prominently keeled. All scale bars represent 5 mm.

num T. Sugaw., occurs in only one population (Pop. 6) on Mt. Kinsakubaru. The third species occurs in two populations (Pops. 7, 8) along the Asato River near Wase-Pass in the northern part of the island (Fig. 2).

Asarum nazeanum is distinguished from *A. celsum* in several floral characteristics, such as the shape and size of a calyx tube, the reticulations on the inner surface of the calyx tube, the diameter of the calyx tube entrance, and anther length (Table 2). The difference in the shape of the calyx tube is particularly noticeable. The shape of the calyx tube has often been used for classification at the species level in section *Heterotropa* (Maekawa 1932, Hatusima & Yamahata 1988, Sugawara 2006b, Lu & Wang 2009).

In the shape of the calyx tube, the third species, here named *Asarum tabatanum* T. Sugaw., appears allied with *A. celsum*, but it is clearly separate from *A. celsum* and *A. nazeanum* in the different reticulated ridges, especially in the number of longitudinal ridges on the inner surface of the calyx tube, the length of stylar protuberances, and by the combination of several floral characters (Table 2). The number of longitudinal ridges on the inner surface of the calyx tube usually characterizes some species in section *Heterotropa* (Sugawara 1998, 2006b).

The mean values of several floral characters for these taxa are summarized in Table 2.

Taxonomy

Asarum nazeanum T. Sugaw., **sp. nov.**—Figs. 1B, 3C, 3D, 6B.

Haec species *Asaro celso* valde affinis est, sed tubo calycis obconio et majore, ostio latiore, intus reticulatione elevata prominenti, antheris longioribus distinguitur.

Typus: JAPAN, Kagoshima Pref., Amami City, Kinsakubaru, alt. 350–400m, 27 March 2005, *T. Sugawara 5032736* (holo: MAK [361294a]; iso- MAK [361294b]).

Herbs, perennial. Rhizomes short. Leaf blade ovate to triangular-ovate, 4–8 cm long, 3–5 cm wide, base cordate, apex slightly acute; upper surface dark green, usually lusterless, variegated or not, sparsely pubescent; lower surface pale green; petiole dark purple, sparsely pubescent, 4–10 cm long. Pedicel 5–10 mm long. Flowers solitary, axillary, opening late February to March, decumbent on ground; pedicel glabrous, ca. 1 cm long; calyx yellow greenish purple or dark purple; calyx tube tubiform, spreading apically, 11–13 mm long, 12–16 mm wide, throat slightly constricted, with a wide orifice ring, opening 3–6.5 mm in diam., orifice usually curved downward, inner surface sharply and prominently tessellated, with longitudinal and transverse ridges, longitudinal ridges 9–12, transverse ridges 4–6; calyx lobes 3, obliquely spreading, triangular, apex slightly acute, 7–12 mm long, 12–17 mm wide, apex subacute, upper surface often bullate and villose, lower surface smooth and glabrous; la-

TABLE 2. Mean value and standard deviation of nine floral characters in three species of *Asarum* on Amami-oshima. Letters (a, b, c) indicate significant differences at $p < 0.05$ by Steel-Dwass's multiple range test.

Character	*A. celsum*	*A. nazeanum*	*A. tabatanum*
Number of individuals examined	31	12	13
Calyx tube length (mm)	8.95 ± 0.87 a	12.16 ± 0.65 b	13.73 ± 1.21 c
Calyx tube width (mm)	9.37 ± 0.90 a	14.42 ± 1.19 b	12.64 ± 1.54 c
Calyx lobe length (mm)	7.92 ± 1.05 a	9.97 ± 1.50 b	11.18 ± 2.14 b
Calyx lobe width (mm)	10.71 ± 1.46 a	14.34 ± 1.36 b	14.12 ± 2.91 b
Diameter of calyx tube entrance (mm)	3.34 ± 1.02 a	4.73 ± 0.95 b	3.12 ± 0.85 a
Number of longitudinal ridges on inner surface of a calyx tube	12.1 ± 0.3 a	11.8 ± 1.3 a	21.7 ± 1.5 b
Anther length (mm) of inner stamen	1.97 ± 0.34 a	2.50 ± 0.15 b	2.39 ± 0.29 b
Anther length (mm) of outer stamen	1.82 ± 0.32 a	2.35 ± 0.16 b	2.30 ± 0.27 b
Stylar protuberance length (mm)	1.19 ± 0.29 a	1.08 ± 0.39 a	1.78 ± 0.27 b

mellate appendages whitish, between orifice and calyx lobes; stamens 12, in 2 whorls of 6, free to base, sessile, 2.5–3.5 mm long; anthers extrorse, longitudinally dehiscing, 2–3 mm long; connective slightly prominent; ovary superior, 6-celled, ovules 10–12 ovules per cell; styles 6, free, erect, apex with horn-like protuberance; protuberances usually 0.5–1.6 mm long, nearly half as long as calyx tube; stigma elliptic, extrorse.

Japanese name. Naze-kan-aoi

Distribution. Japan, southwestern Kyushu, Kagoshima Pref., Amami-oshima, Amami City, around Kinsakubaru. Known only in this area.

Etymology. This specific epithet refers to the name of the old town, Naze, on Amami-oshima, where the type specimen was collected.

Asarum tabatanum T. Sugaw., **sp. nov.**—Figs. 1A, 3E, 3F, 6C.

Haec species *Asaro celso* valde affinis est, sed tubo calycis majore, intus reticulatione elevata complesa, protuberantia stylo longioribus, antheris longioribus distinguitur.

Typus. Japan, Kagoshima Pref., Amami City, near Wase Pass, along the Asato River, alt. 150–200 m, 7 March 2008, *T. Sugawara & M. Tabata 8030704* (holo-MAK [397482]).

Herbs, perennial. Rhizomes short. Leaf blade triangular-ovate to ovate, 5–10 cm long, 4–7 cm wide, base cordate, apex slightly acute; upper surface dark green to green, lusterless, variegated or not, margin sparsely pubescent; lower surface pale green, sparsely pubescent on midrib; petiole dark purple, sparsely pubescent, 5–10 cm long. Pedicel glabrous, 5–10 mm long. Flowers solitary, axillary, opening late February to March, decumbent on ground; calyx dark purple or greenish purple; calyx tube campanulate, 12–16 mm long, 10–15 mm wide in middle, throat with a wide orifice ring, opening narrowly, 1.5–5 mm in diam., inner surface usually with complicated and sharply tessellated longitudinal and transverse ridges, longitudinal ridges usually 19–24, transverse ridges 5–8; calyx lobes 3, horizontally spreading, triangular-ovate, apex subacute, 9–15 mm long, 11–19 mm wide, upper surface villose, lower surface smooth and glabrous, lamellate appendages present between orifice and calyx lobes; stamens 12, in 2 whorls of 6, free to base, sessile, 2–3.5 mm long; anthers extrorse, longitudinally dehiscing, 1.8–3 mm long, connectives slightly prominent; ovary superior, 6-celled, ovules 10–12 per cell; styles 6, free, erect, apex with horn-like protuberance; protuberances 1.3–2.2 mm long, nearly half as long as calyx tube; stigma elliptic, extrorse.

Japanese name. Asato-kan-aoi

Distribution. Japan, southwestern Kyushu, Kagoshima Pref., Amami-oshima, Amami City, along the Asato River.

Other specimen examined. JAPAN, Kyushu, Kagoshima Pref., Amami City, near Wase Pass, alt. 150–200 m, 7 March 2008, *T. Sugawara & M. Tabata 8030709* (MAK [397481]).

Etymology. The specific epithet honors Mr. Mitsutake Tabata who first discovered the unknown plants of *Asarum* on Amami-oshima.

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